Efficient Linearized Photonic Crystal Semiconductor Optical Modulators

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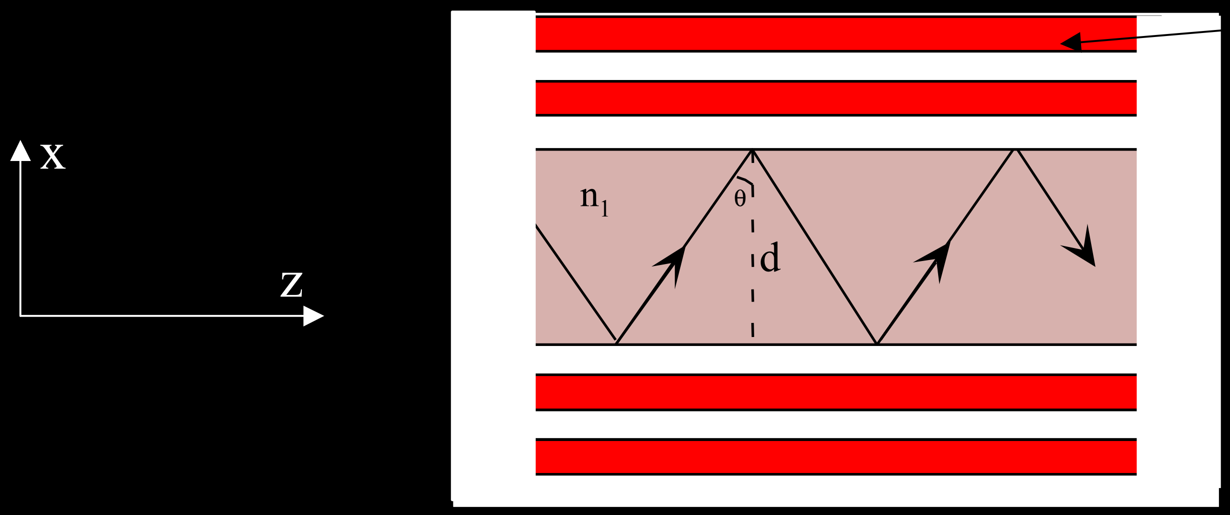
Basic Modulator Idea

The modulator works by modulating the effective index of the waveguide mode in a Mach-Zehnder structure. In other words, we are modulating the waveguide dispersion.

We electro-optically modulate the cladding index. Then we take advantage of the steep relationship between the phase of the reflectivity from the core-cladding interface and the wavelength.

Reflectivity phase changes cause a change in the transverse mode profile. The modal index changes as the transverse mode profile expands and contracts.

Transverse resonance condition: the roundtrip phase in the x-direction must be a multiple of 2π



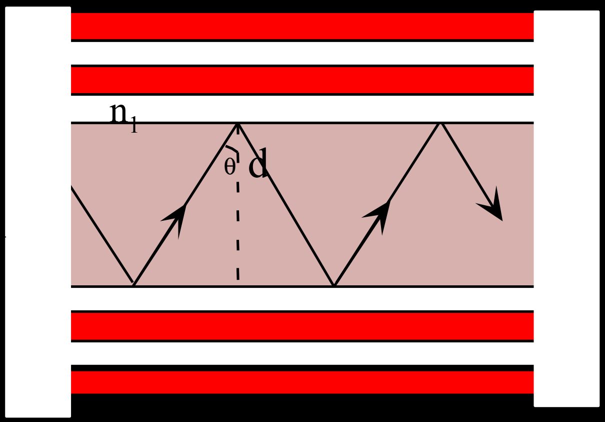
$$2d\left(\frac{2\pi n_1}{\lambda}\cos\theta\right) + 2\varphi(\lambda) = 2m\pi$$

x-component of the wave vector

phase of the reflection coefficient

Phase along the z-direction

$$\boxed{k\sin\theta\cdot z}$$



In one "roundtrip" the phase along z is

$$\boxed{k\sin\theta(2d\tan\theta)+2\varphi}$$

The phase per unit length is

$$\frac{k\sin\theta(2d\tan\theta)+2\varphi}{2d\tan\theta}=k\sin\theta+\frac{\varphi}{d}\cot\theta$$

For complete modulation we want $\Delta kL=\pi$

$$\Delta k=\frac{dk}{dn}\Delta n=\frac{2\pi\Delta n}{\lambda}\sin\theta+\frac{2\pi n\Delta n}{\lambda}\cos\theta\frac{d\theta}{dn}+\frac{d\varphi}{dn}\frac{\Delta n}{d}\cot\theta-\frac{\varphi}{d}\csc^2\theta\frac{d\theta}{dn}\Delta n$$

V_π Estimate

$d = 0.16\ \mu m$	$n=3.5$	$\Theta=45^o$
$\phi \sim 85^o$	$L = 1.5 \mu m$	$r_{41}=-1.4x10^{-10}$ cm/V
L=1mm	push-pull	$d\phi/d\lambda = 11^o/nm$

$V_\pi = 0.48$ V for field applied over 1 μm

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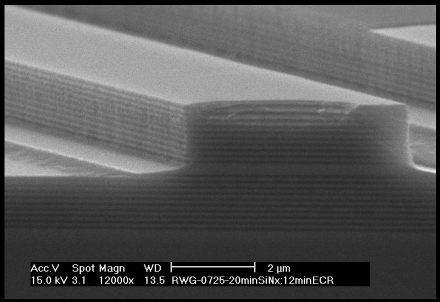
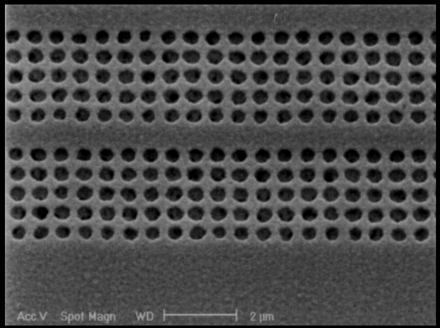
Hierarchy of Structures

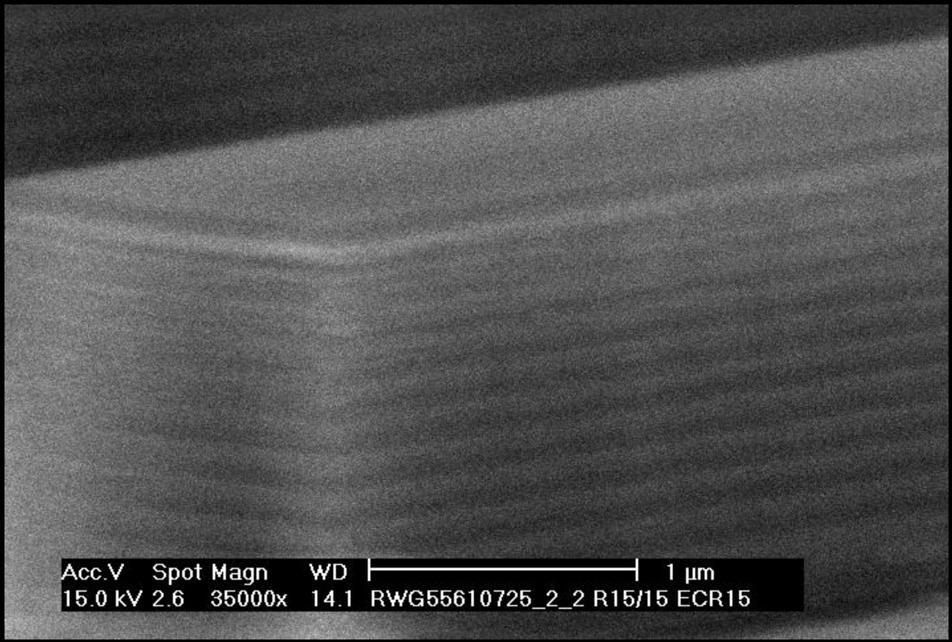


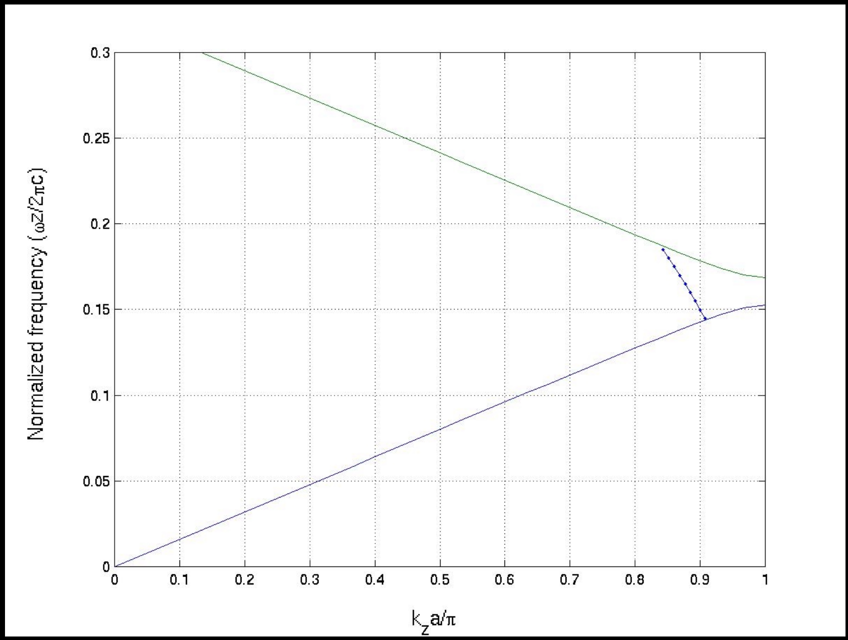
1D vertical guiding - This is the simplest implementation. The structure will be thick and therefore require larger voltages.



2D transverse guiding - This design allows the most freedom to design V_π and linearity.

Phase Modulators With One-Dimensionally Periodic Cladding Layers





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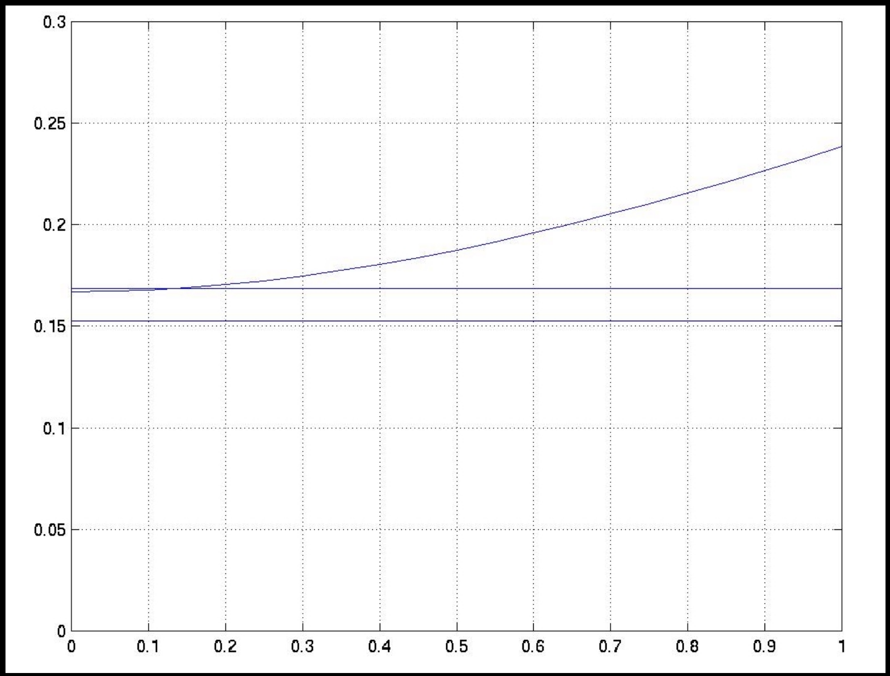
ω-β in for Guided Mode in Phase Modulator

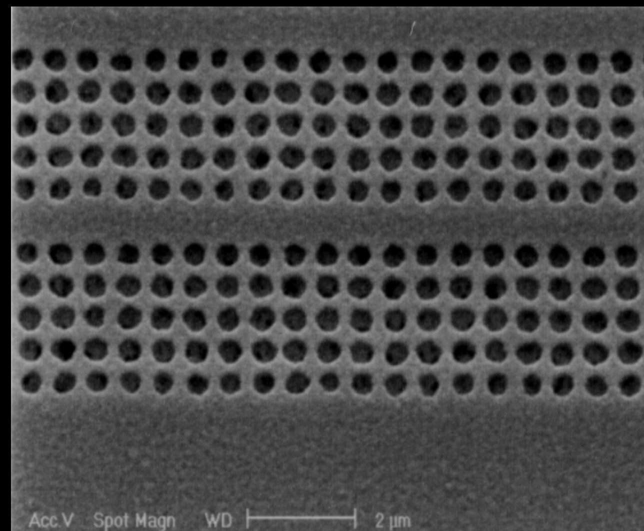
Normalized Frequency

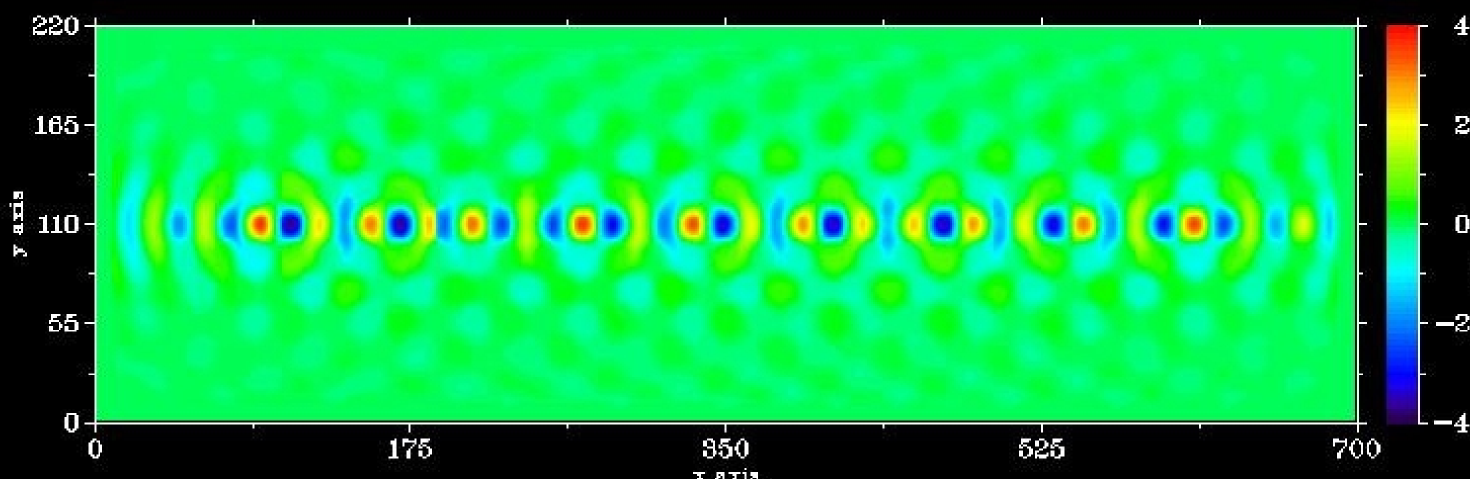


Normalized Propagation Constant

d_{core} = 0.301 μm
d_1 = 0.122 μm
d_2 = 0.142 μm
n_1 (GaAs) = 3.37
n_2(AlAs) = 2.89

Mach-Zehnder Implementation Using Two-Dimensional Photonic Crystals





Finite-Difference Time-Domain Calculation of the Amplitude of the Magnetic Field Inside a Photonic Crystal Waveguide

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Challenges Presented by Mach-Zehnder Implementation in Photonic Crystals

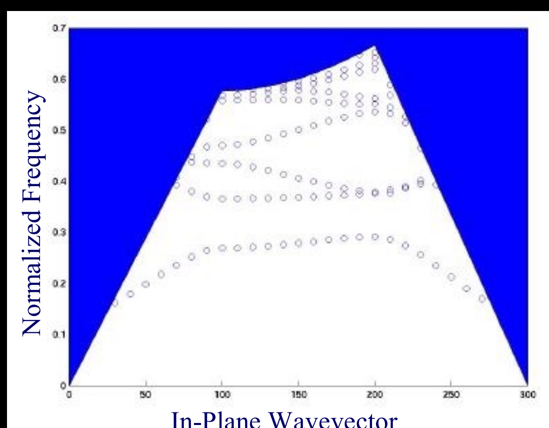
- Low loss, low reflectivity symmetric Y-branch

- Low loss, low reflectivity waveguide bends

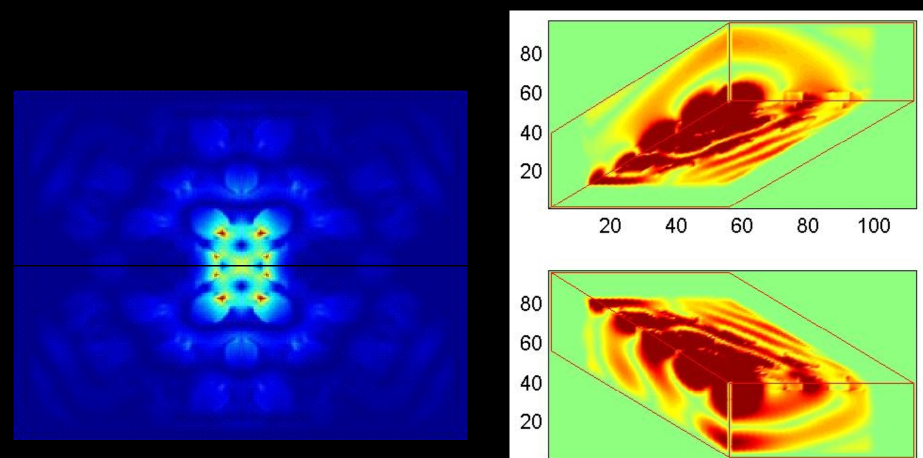
Numerical Tools

- Finite-Difference Time-Domain
  10 workstation, 18 processor parallel system linked by MPI

- Finite Element Method



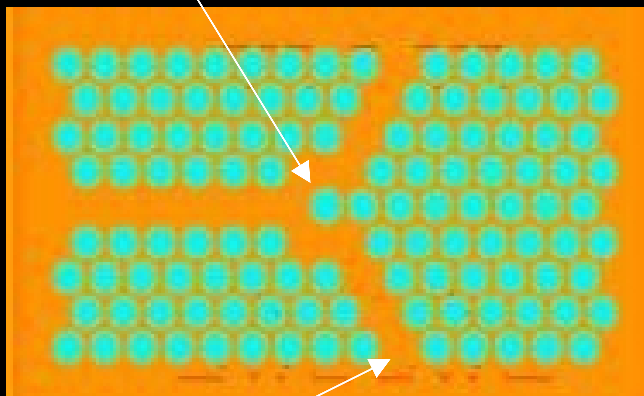
Bandstructure and dispersion relations



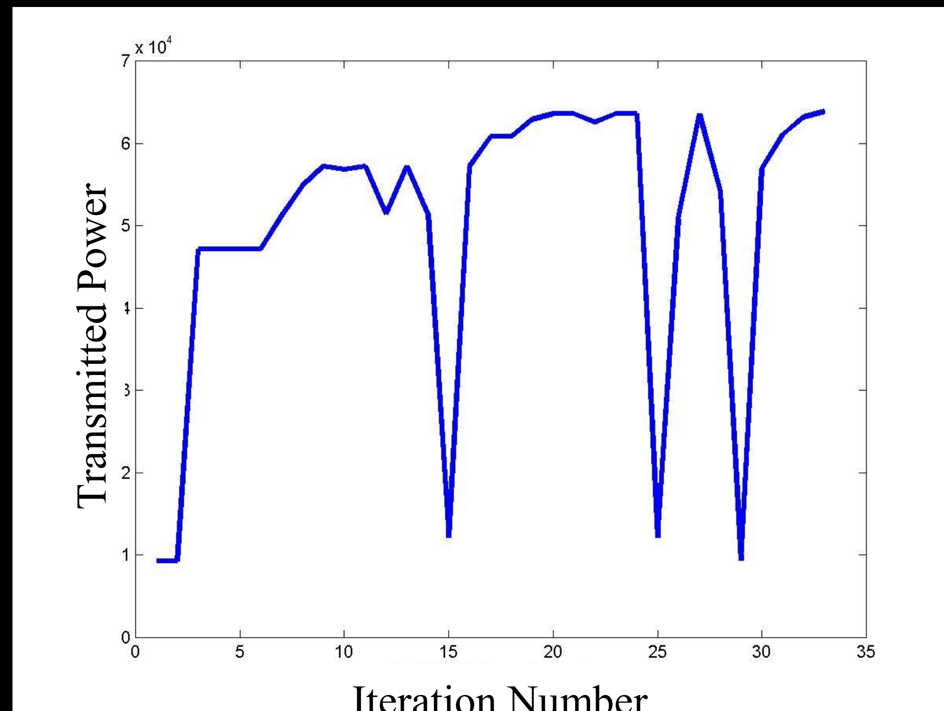
Two and three-dimensional field calculations

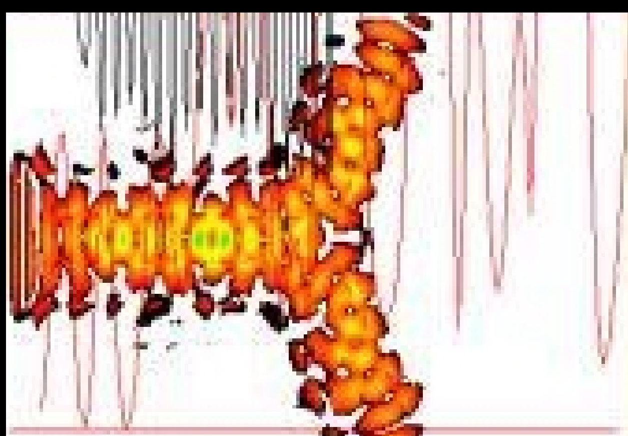
Optimization Algorithm for Designing Photonic Crystals

position and size of this hole varied



power transmitted optimized here





Powell Algorithm for Multidimensional Optimization

Will find local maxima

Preliminary demonstration varied radius and position of one hole controlling the resonant coupling

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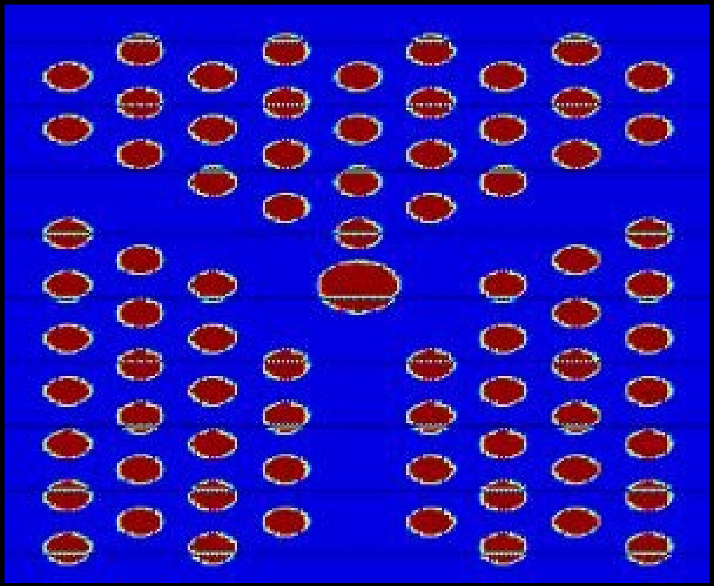
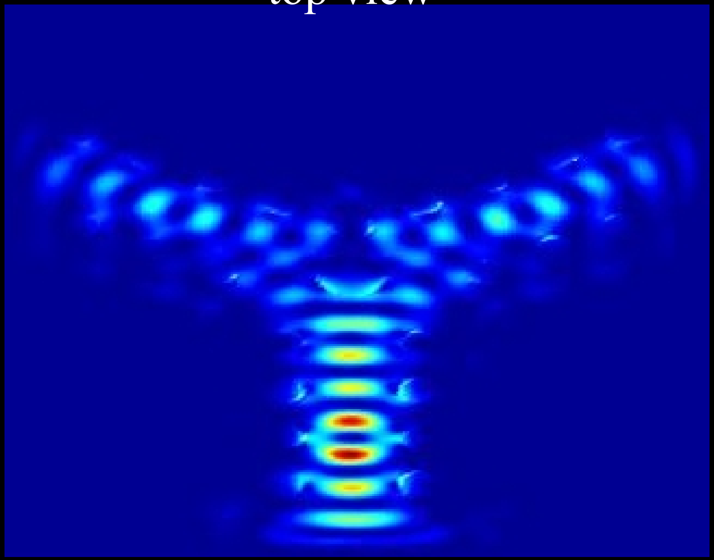
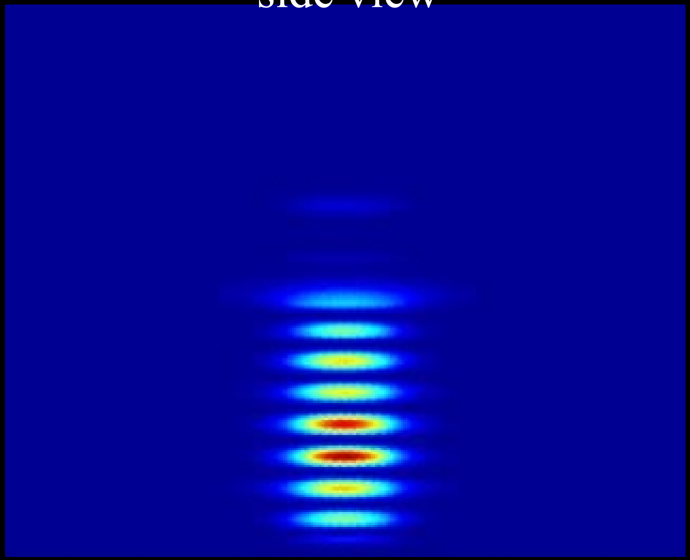
Three-Dimensional FDTD Simulation of a Photonic Crystal Y-Branch



top view



side view



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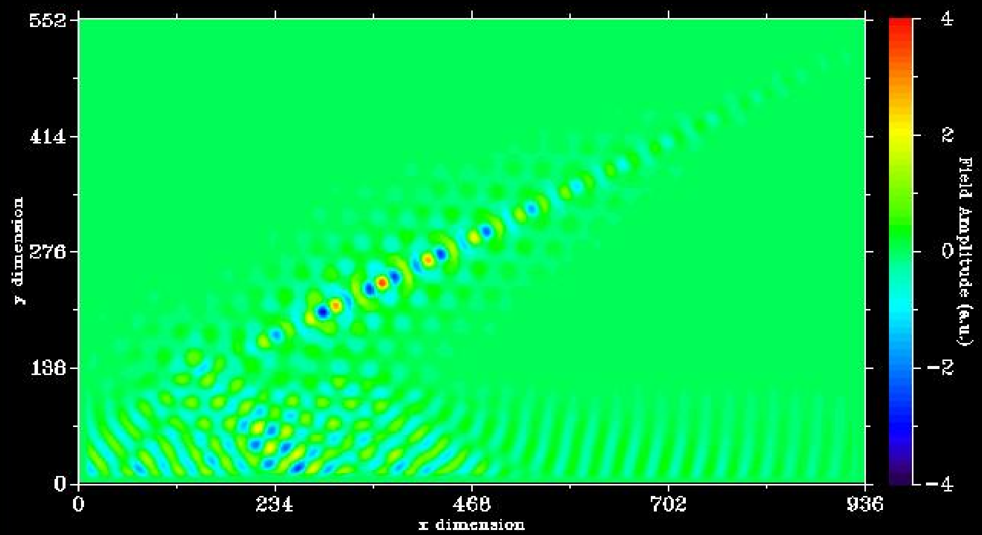
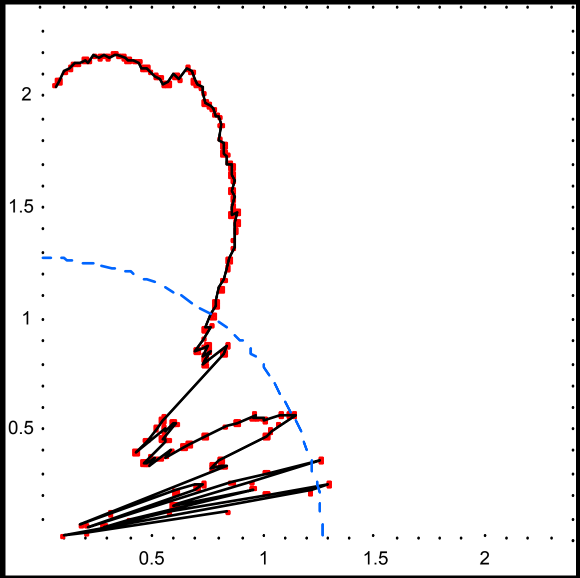
Angular Input Acceptance

FDTD Calculation of an Optical Pulse Incident on an Angled Photonic Crystal Waveguide



Polar Plot of Coupled Power as a Function of Waveguide Angle



Summary

• Phase modulator with one-dimensional periodic cladding is designed and ready to fabricate.

• The Mach-Zehnder junctions for the two-dimensional photonic crystal amplitude modulator are designed.

• We are working to simplify the photonic crystal waveguide fabrication process by using a buried mask.